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DLC COATING FOR EARTH-BORING BIT BEARINGS

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Cross-Reference to Related Application

This invention is a continuation-in-part of application serial number 10/223,533, filed August 19, 2002.

Field of the Invention

This invention relates in general to earth-boring bits, especially the bearings for earth-boring bits of the rolling cone variety. More particularly, the invention relates to coatings on the bearings for enhancing wear resistance.

Background Information

In drilling boreholes in earthen formations by the rotary method, earth-boring bits typically employ at least one rolling cone cutter, rotatably mounted thereon. The bit is secured to

the lower end of a drillstring that is rotated from the surface or by downhole motors. The cutters mounted on the bit roll and slide upon the bottom of the borehole as the drillstring is rotated, thereby engaging and disintegrating the formation material. The rolling cutters are provided with teeth that are forced to penetrate and gouge the bottom of the borehole by weight from the drillstring.

As the cutters roll and slide along the bottom of the borehole, the cutters, and the shafts on which they are rotatably mounted, are subjected to large static loads from the weight on the bit, and large transient or shock loads encountered as the cutters roll and slide along the uneven surface of the bottom of the borehole. Thus, most earth-boring bits are provided with precision-formed journal bearings and bearing surfaces, as well as sealed lubrication systems to increase drilling life of bits. The lubrication systems typically are sealed to avoid lubricant loss and to prevent contamination of the bearings by foreign matter such as abrasive particles encountered in the borehole. A pressure compensator system minimizes pressure differential across the seal so that the lubricant pressure is equal to or slightly greater than the hydrostatic pressure in the annular space between the bit and the sidewall of the borehole.

The bearing surfaces include a thrust shoulder formed on the bearing pin perpendicular to the axis of the bearing pin. A mating thrust shoulder is formed in the cavity of the cone. A partially cylindrical journal bearing surface is formed around part of the bearing pin for engaging a mating surface in the cavity of the cone. In the past, inlays of a hard material, such as Stellite, have been placed on the thrust shoulder and on the journal bearing surface. Also, a hardened ring has been mounted in the cavity of the cone for engaging the inlay on the journal bearing surface.

Very hard, wear-resistant layers and coatings have been developed for a variety of purposes, such as those employing diamond. These coatings, however, generally need to be

applied at high temperatures and high pressures and are applied after the steel member has been hardened. If the high temperatures exceed the lowest transformation temperature of the steel member, such as the temperature at which the steel member has been tempered, this would adversely affect the properties of the seal member.

U.S. Patent 6,209,185 to Scott discloses applying a diamond layer to a substrate, then attaching the diamond layer to a rigid seal ring. This avoids having to heat the hardened ring beyond its lowest transformation temperature, but it does require attachment by brazing, epoxy or the like. U.S. 6,045,029 to Scott discloses forming a diamond layer directly on a rigid seal ring by a process that is accomplished at a temperature lower than the lowest transformation temperature of the metal of the seal ring. This may be done in an amorphic diamond process or by forming the diamond layer separately and attaching it to the rigid ring of the seal.

Summary of the Invention

In this invention, rather than a diamond coating, a diamond-like coating (DLC) is applied. A DLC coating is a form of meta-stable amorphous carbon or hydrocarbon polymer with properties very similar to those of diamond. It is a vapor deposited carbon coating with a mixture of sp3 and sp2 bonds between the carbon atoms and could be doped with one or more alloying elements such as silicon, boron, boron nitride, and one ore more refractory metallic elements, such as tantalum, titanium, tungsten, niobium or zirconium,. The designation sp3 refers to the tetrahedral bond of carbon in diamond, while the designation sp2 is the type of bond in graphite. As DLC has a certain percentage of both, the hardness is less than diamond and between diamond and graphite.

The DLC coating is applied to the seal face of a bearing member after it has been hardened and tempered. It is applied at a temperature lower than the lowest transformation temperature so as to not detrimentally affect the dimensions or hardness of the substrate body of the thrust member. In one process, it is performed by the decomposition of a carbon and hydrogen compound, such as acetylene, in the presence of a plasma. The process is carried out until the coating has a thickness in the range from about 1 to 10 micrometers. The Knoop scale hardness is in the range from 2,000 to 5,000.

In one embodiment, the bearing member that has the DLC coating comprises a thrust washer that locates between the thrust shoulders of the bearing pin and the cone. Also, the bearing sleeve that fits in the cone and engages the bearing pin preferably contains a DLC coating on at least one side. In the first embodiment, the bearing pin thrust shoulder and journal bearing surface have inlays of a hard, wear resistant material such as Stellite. In an alternate

embodiment, the DLC coating is also applied to the bearing pin thrust shoulder and journal bearing surface.

Brief Description of the Drawings

Figure 1 is a sectional view of a portion of an earth-boring bit constructed in accordance with this invention.

Figure 2 is a perspective view of a journal bearing sleeve of the bit of Figure 1.

Figure 3 is a perspective view of a thrust washer of the bit of Figure 1.

Figure 4 is a schematic sectional view of a portion of the thrust washer of Figure 3.

Figure 5 is a side view of part of a bearing pin of an alternate embodiment.

Figure 6 is a graph illustrating a thrust wear test.

Detailed Description of the Invention

Referring to Figure 1, bit 11 has at least one bit leg 13 and normally three. Each bit leg 13 has a bearing pin 15 that extends downward and inward toward an axis of rotation of bit 11. Bearing pin 15 has a cylindrical nose 17 on an inner end that is of lesser diameter than remaining portions of bearing pin 15. An inward facing annular thrust shoulder 19 surrounds nose 17. Thrust shoulder 19 is located in a plane perpendicular to an axis of bearing pin 15. In this embodiment, thrust shoulder 19 optionally has an inlay 21 of a hard, wear resistant material, such as Stellite. Similarly nose 17 may have an inlay 23 of the same wear resistant material on its cylindrical exterior.

Bearing pin 15 has a partially cylindrical journal bearing surface 25 that extends around its lower side. In this embodiment, an optional inlay 27 of a hard wear resistant material, such as Stellite, is located in journal bearing surface 25. Since the thrust imposed on bit 11 is downward, inlay 27 does not extend to the upper side of bearing pin 15. Inlays 21 and 23 could be omitted if desired. A lubricant passage 29 extends through bit leg 13 and bearing pin 15 to the upper side of bearing pin 15. A pressure compensator (not shown) supplies pressurized lubricant to passage 29.

A cutter or cone 31 mounts rotatably to bearing pin 15. Cone 31 has a plurality of teeth 33 on its exterior. Figure 1 shows teeth 33 from all three cones 31 of bit 11 rotated into a single plane. Teeth 33 may be hard metal inserts pressed into mating holes in the body of cone 31, as shown. Alternately, they may be steel teeth milled into the exterior of cone 31.

Cone 31 has a central cavity 35 for rotatably mounting on bearing pin 15. Cavity 35 has a thrust shoulder 37 that is perpendicular to the axis of cone 31 for mating with bearing pin thrust shoulder 19. A thrust washer 39 is located between thrust shoulders 19 and 37. In the preferred embodiment, thrust washer 39 is not fixed to either thrust shoulder 19 or 37, although it could be brazed or welded to one of the shoulders 19 or 37.

A bearing sleeve 41 is located in the cavity of cone 31 in this embodiment to serve as part of a seal assembly. As shown in Figure 2, bearing sleeve 41 preferably does not extend entirely 360 degrees, rather has a gap or slit on its upper side. Bearing sleeve 41 rotates with cone 31 and slidingly engages journal bearing inlay 47 in this embodiment. A retainer ring 43 extends around cavity 35 in engagement with a retaining groove 45 to hold cone 31 on bearing pin 15. Another type of retainer uses balls. A seal assembly 47 seals the outer end of cavity 35 to bearing pin 15.

Thrust washer 39 and bearing sleeve 41 are preferably formed of a hardened ferrous metal selected from the group consisting essentially of iron with cobalt and alloys thereof, such as stainless steel or Stellite. The material of thrust washer 39 and bearing sleeve 41 has a lowest transformation temperature, which is considered to be a temperature at which the metal at least partially loses its properties as a hardened metal.

As illustrated in Figure 4, a coating 49 of DLC material is applied to at least one of the faces, preferably both, of thrust washer 39. The thickness of coating 49 is greatly exaggerated in Figure 4. A similar DLC coating is optionally applied to the inner diameter of bearing sleeve 41. As discussed above, DLC, or diamond-like carbon, is a form of meta-stable amorphous carbon or hydrocarbon compound with properties very similar to those of diamond. Being amorphous, there are no grain boundaries. DLC coating is a carbon coating with a mixture of sp3 and sp2

bonds between the carbon atoms. The sp3 bond is a tetrahedral bond of carbon that forms diamond. The sp2 bond is of a type that forms graphite. Technically, the sp3 bond means that the carbon reconfigures one s-orbit and three p-orbits to form four identical orbits in a tetrahedral configuration for bonding to the next carbon atom. The sp2 bond is the hybridization of one s and two p-orbits to three sp2 orbits, which are planar. DLC has a certain percentage of both types of bonds, thus the hardness is between diamond and graphite. The proportions of sp2 and sp3 can be varied. In addition to carbon, there is a certain amount of hydrogen in the DLC coatings. The hydrogen content comes from the process gas used, since normally DLC coatings are deposited by the decomposition of a carbon and hydrogen compound. One acceptable compound is acetylene. Also, the DLC coating may be doped with one or more alloying elements such as silicon, boron, boron nitride and one or more refractory metallic elements, such as tantalum, titanium, tungsten, niobium or zirconium.

Thrust washer 39 and bearing sleeve 41 are first hardened, tempered and formed to the desired dimensions. Portions of thrust washer 39 and bearing sleeve 41 that are not to be coated are masked off. One process to apply the DLC coating comprises depositing material from an RF (radio frequency) plasma, sustained in hydrocarbon gases, onto negatively biased thrust washer 39 and bearing sleeve 41. In this process, referred to as plasma assisted chemical vapor deposition or PACVD, thrust washer 39 and bearing sleeve 41 are heated by an electron current to a temperature below their lowest transformation temperatures. Electrons from the electron current are attracted to the exposed portions of thrust washer 39 and bearing sleeve 41 from a plasma beam in the center of the chamber. After heating, the exposed portions are etched by argon ion bombardment. For this etching process, thrust washer 39 and bearing sleeve 41 are

biased to a negative potential to attract argon ions from a plasma source. This process cleans the exposed surfaces by etching.

Afterward, one or more metallic interlayers, usually chromium, is applied from a sputter source such as a chromium target. Sputtering is a similar process to etching, but a bias voltage is applied to the chromium target of several hundred volts. The exposed surfaces of thrust washer 39 and bearing sleeve 41 serve as a negative electrode. Material is removed from the chromium target surface by the impact of argon ions. This material condenses on the exposed surfaces. The metallic interlayer is used to increase adhesion and could be formed of other metals such as titanium.

After the interlayer is laid, acetylene is introduced and a plasma is ignited between the exposed surfaces of thrust washer 39 and bearing sleeve 41 and the chamber walls. The acetylene decomposes to form carbon atoms that coat the exposed surfaces on the metallic interlayer with DLC. DLC coatings are insulating, thus the plasma for the DLC cannot be a DC plasma, but must be an AC plasma. Typically an RF plasma is used. After coating, thrust washer 39 and bearing sleeve 41 are cooled before venting the chamber. During the entire coating process, the temperature will be maintained below the lowest transformation temperature of thrust washer 39 and bearing sleeve 41.

In addition to the process described above, other processes are suitable, including primary ion beam deposition of carbon items (IBD). Another process that may be suitable is sputter deposition of carbon with or without bombardment by an intense flux of ions (physical vapor deposition). Another technique is based on closed field unbalanced magnetron sputter ion plating

combined with plasma assisted chemical vapor deposition. The deposition is carried out at approximately 200°C in a closed field unbalanced magnetron sputter ion plating system.

DLC coating 49 preferably has a thickness in the range from 1 to 10 micrometers, preferably 2 to 5 micrometers and, even more specifically, 2 to 3 micrometers. The hardness is in the range from 2,000 from 5,000 Knoop, thus not as hard as diamond. Once the coatings are formed on thrust washer 39 and thrust washer 41, these members are installed in cone cavity 35. Cutter or cone 31 is installed on bearing pin 15 in a conventional manner.

Laboratory tests have been conducted to demonstrate the performance of the coating. First, thrust washer pressure-velocity tests were carried out. In one test, an uncoated stainless steel 440C thrust washer ran against a mating surface that was coated with DLC to a thickness of 2 to 3 micrometers. This pressure velocity tests showed that the DLC coating more than doubled the load carrying capacity of the component. The average load at the pressure velocity limit for the standard was 1.6 million Newtons millimeter per second , while the DLC coating had an average load at the pressure velocity limit of greater than 4.3 million Newtons millimeter per second.

Then, a wear test was carried out to demonstrate the wear resistance of the DLC coating. The results are shown in Figure 6. The designation TW1 top and low refers to two thrust washers rotated against one another, with one of the thrust washers having a DLC coating and the other being uncoated 440C stainless steel. When rotated against one another, the TW1 thrust washers exhibited very little weight loss after a two-hour test interrupted at 30 minute intervals (1800 seconds) to make a weight loss measurement. The other specimens, designated TW2, had

both top and bottom washers of 440C stainless steel without any DLC coatings. The bottom or lower thrust washer wore significantly during the two-hour test.

In the embodiment of Figure 5, bearing pin 51 does not have a thrust shoulder inlay 21 or journal bearing inlay 27 as in Figure 1. Instead, a DLC coating 53 is directly applied to the journal bearing of bearing pin 51. A DLC coating 55 is directly applied to the thrust shoulder of bearing pin 51. DLC coatings 53, 55 are applied in the same manner as described above and replace inlays 21 and 27. Thrust washer 39 (Figure 1) preferably has a DLC coating as previously described and slidingly engages thrust shoulder DLC coating 55. The DLC coatings 41 and 55 are thus in sliding engagement with each other. Alternately, the DLC coatings could be in the cavity of the cone and on bearing pin 51, and thrust washer 39 could be conventional without DLC coatings.

As additional alternates, bearing sleeve 41 (Figure 1) may have a DLC coating on its inner diameter as previously described that slidingly engages DLC coating 53. As an another alternate embodiment, a DLC coating could be applied to the outer diameter of bearing sleeve 41 and to the inner diameter of the cavity in cone 31 (Fig. 1). In this arrangement, bearing sleeve 41 would be rotatable relative to cone 31. In such case, bearing sleeve 41 could either have DLC coatings on both sides or no DLC coatings at all.

The invention has significant advantages. The DLC coating is applied in a process that does not detract from the properties of the substrate. The DLC coating exhibits high wear resistance, with the graphite component in the DLC coating enhancing lubrication.

While the invention has been shown in only two of its forms, it should be apparent to those skilled in the art that it is not so limited but is susceptible to various changes without departing from the scope of the invention.